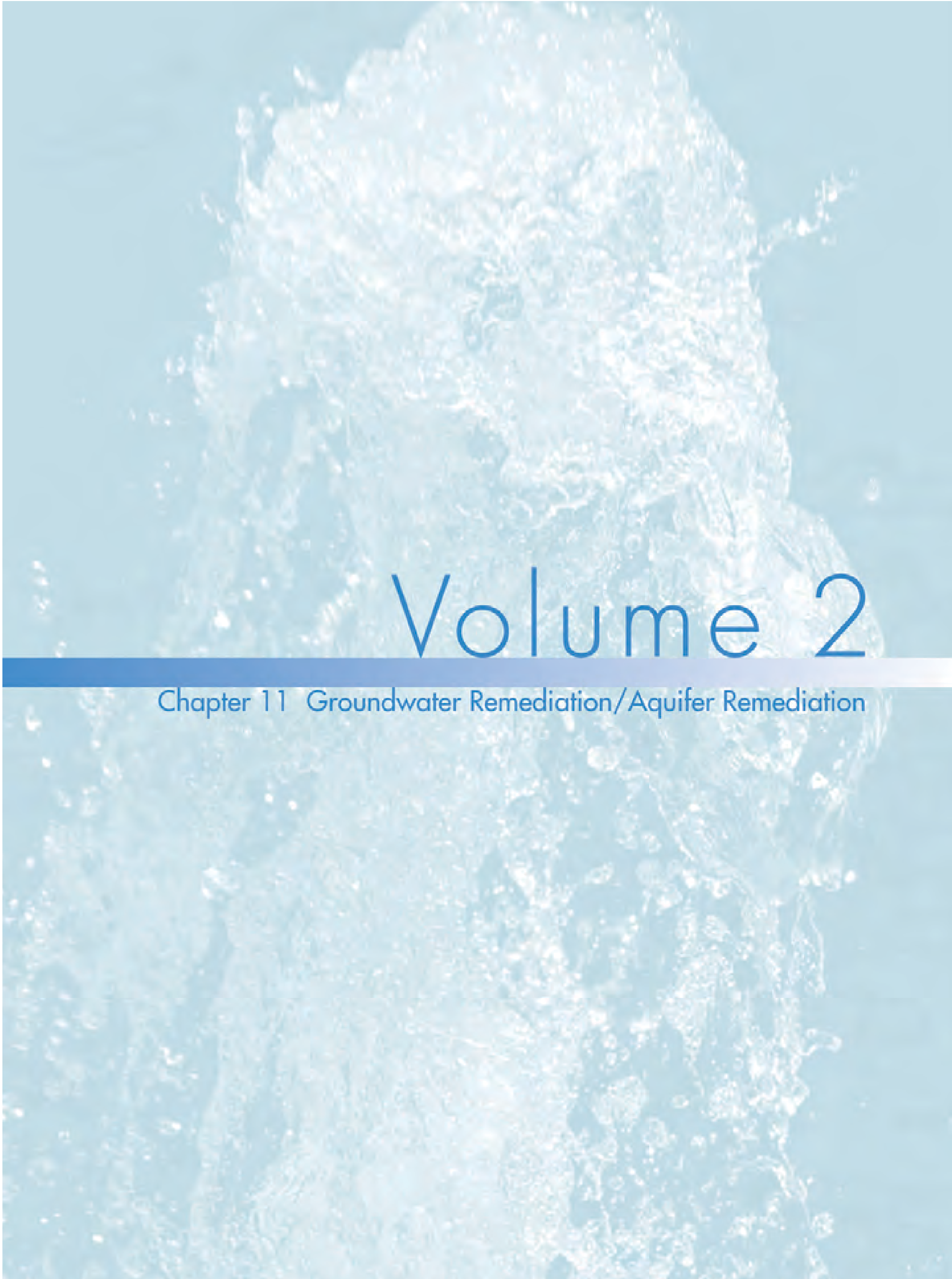

Volume 2

Chapter 11 Groundwater Remediation/Aquifer Remediation

Chapter 11 *Groundwater Remediation/Aquifer Remediation*

Groundwater remediation involves extracting contaminated groundwater from the aquifer, treating it, and discharging it to a water course or using it for some purpose. It is also possible to inject the treated water back into the aquifer. Contaminated groundwater can result from a multitude of sources, both naturally occurring and anthropogenic. Examples of naturally occurring contaminants include heavy metals, high total dissolved solids, and high salinity from specific geologic formations or conditions. Groundwater can also be contaminated from anthropogenic sources with organic constituents, inorganic constituents, and radioactive constituents from many point and non-point sources. These anthropogenic sources include industrial sites, mining operations, leaking tanks and pipelines, landfills, impoundments, dairies, agricultural and storm runoff, and septic systems.

In the process of groundwater remediation, the groundwater flows through the aquifer toward the extraction wells where it is removed for treatment. If recharge of the aquifer continues, this flow provides a flushing action that may eventually remove most of the contaminants from the aquifer. This is also called the "pump and treat" method of remediation. Pump and treat methods transfer the contaminant to either the atmosphere or a filter material. If a volatile material is transferred from the groundwater to the atmosphere, permits must be obtained from the appropriate air pollution control district or agency for the amount to be transferred. If a filtration medium is used, such as granular activated carbon (GAC), the GAC must be disposed of as a hazardous waste. If the GAC is regenerated, the waste from that process must be disposed of as a hazardous waste. If the contaminant is radioactive, such as uranium, then residuals may need to be disposed of as radioactive waste.

Aquifer remediation is usually accomplished by treating the groundwater while it is still in the aquifer, using in situ methods involving physical or chemical treatment, biological treatment, or electrokinetics.

Another term used for either groundwater or aquifer remediation processes is groundwater restoration. Whatever the treatment method (see Table 11-1), it must be suited to the chemical (see Table 11-2) that has contaminated the aquifer. Light, non-aqueous phase liquids (LNAPLs), such as hydrocarbons, float on the surface of the groundwater. Dense, non-aqueous phase liquids (DNAPLs), such as trichloroethylene (TCE) have a specific gravity greater than water and sink to the bottom of the aquifer. Other contaminants, such as methyl tertiary butyl ether (MTBE), may be miscible in water and are in solution in the groundwater. Even with LNAPLs and DNAPLs, some of the contaminant dissolves within the groundwater in the aquifer.

Information for this entire narrative was provided by California Department of Health Services, Division of Drinking Water and Environmental Management; and by California State Water Resources Control Board, Division of Clean Water Programs.

Groundwater Remediation in California

Most remediation in California involves groundwater remediation; very little aquifer remediation takes place. There are about 18,500 sites in the state where active cleanup of contaminants is ongoing. Regulatory oversight of these cleanups is by Regional Water Quality Control Boards (Regional Boards), the Department of Toxic Substances Control (DTSC) or local agencies. About 15,000 of these sites have had a petroleum release from a leaking underground storage tank (UST) system. A petroleum release is usually detected by analyzing for total petroleum hydrocarbons (TPH) and the more soluble constituents in fuel (benzene, toluene, ethyl benzene, and xylene, commonly called BTEX). In addition to these, MTBE can be found at former leaking UST sites. Groundwater cleanup at petroleum sites almost always focuses on reduction of BTEX and MTBE because most other components of petroleum are slightly soluble in water and do not migrate far from the original source of the leak.

Table 11-1 Types of treatment

Pump and treat – groundwater remediation
Activated alumina
Biological
Blending
Coagulation/filtration
Granular activated carbon, GAC
Ion exchange, IX
Lime softening
Packed tower aeration (air stripping)
Reverse osmosis, RO
Ultra-violet photoionization
In-situ – aquifer remediation
Air sparging
Bio-sparging
Bio-venting
Cosolvents
Electrokinetics
Electron acceptors (nitrate, sulfate, ferric ions)
Electron donors (to degrade chlorinated hydrocarbons)
Fluid cycling
Hydrofracturing/Pneumatic fracturing
Soil vapor extraction
Surfactant enhancements
Thermal enhancements
Treatment walls
Vitrification

Table 11-2 List of contaminants[1]

1,2-Dibromo-3-chloropropane, DBCP
1,2-Dichloroethane
1,2,3-Trichloropropane, 1,2,3-TCP
Arsenic, As
Carbon tetrachloride, CTC
Ethylene dibromide, EDB
Methyl tertiary butyl ether, MTBE
N-Nitrosodimethylamine, NDMA
Nitrate as NO3
Nitrate + Nitrite as N
Perchlorate, ClO4
Tetrachloroethylene, PCE
Total petroleum hydrocarbons, TPH e.g, hexane, jet fuels, mineral oils, benzene toluene, xylenes, naphthalene, fluorene
Trichloroethylene, TCE
Uranium, U

[1] Some may also be called by other names

In general, cleanup for the vast majority of contaminant sites involves excavation, free-product removal if applicable, soil vapor extraction, in situ remediation, or a combination of these remediation methods. Pump and treat methodology tends to be expensive and is not employed when other effective remediation options are available. The discharge from a pump and treat system may also require a discharge permit issued by a Regional Board.

About 800 sites in California use pump and treat systems. And about a third of these are at UST sites, where shallow groundwater is typically affected. The treated-flow volumes are on the order of 10-20 gallons per minute. At a small number of sites the volume treated can be millions of gallons per day.

Volatile organic compounds (VOCs) such as TCE and tetrachloroethylene (PCE) (see Table 11-1) are being removed from groundwater in Los Angeles, from the San Gabriel basin. VOCs are also being removed in Santa Clara County. Often these cleanups are associated with federal Superfund projects, for example, the Glendale Operable Unit (OU), or the Burbank OU.

Perchlorate is being removed by ion exchange and biological treatment in Sacramento and San Gabriel basins. In Sacramento and Santa Clara, the treated water is released into a surface water channel, whereas in San Gabriel, the treated water is pumped into the public water supply distribution system.

Besides the groundwater remediation projects mentioned above, there are drinking water treatment projects for VOCs, including TCE, PCE, that are operating in various water systems (see Table 11-3). The gasoline additive MTBE is being treated in the city of Santa Monica, and in several smaller systems. Arsenic treatment is occurring in a few water systems to meet the current Maximum Contaminant Level (MCL) of 50 micrograms per liter. In 2006, the new federal MCL of 10 micrograms per liter becomes effective, and it is predicted that additional water systems will be required to treat to remove arsenic systems. Pesticides, especially 1,2-dibromo-3-chloropropane (DBCP) and ethylene dibromide (EDB), are being removed in the San Joaquin Valley and Southern California.

Nitrates in groundwater are being blended or treated in most areas of the state where agriculture has been active, either in the past or today, and wherever there are high concentrations of septic tank treatment and disposal systems.

Table 11-3 Locations of groundwater sources of drinking water with selected detected contaminants. Information provided by California Department of Health Services, Division of Drinking Water and Environmental Management

Contaminant	Counties Affected (# of sources with detections)[1]	Types of Treatment Used	Examples: Water Systems to Contact for Additional Information
Regulated Contaminants			
Inorganic Chemicals			
Arsenic (current MCL – 50 ppb[2]	Kern (10), Kings (13), San Bernardino (7), Sonoma (6), Nevada (5), Sutter (5), Los Angeles (4), Mono (4)	activated alumina; ion exchange (IX), reverse osmosis (RO), (others with limitations—see 22 CCR § 64447.2), blending	Edgemont Acres MWD; Boron CSD; Mt. Weske Estates MWC; City of Signal Hill
Arsenic (federal MCL, effective 2006 = 10 ppb)[2]	Kern (115), San Bernardino (70), Los Angeles (58), San Joaquin (56), Kings (37), Sacramento (37), Sutter (29), Sonoma (24), Riverside (20), Madera (15), Monterey (14), Fresno (13), Nevada (12), Tulare (12), Merced (10), Mono (9), Stanislaus (9), Napa (8)		
Nitrate as NO3	Los Angeles (171), San Bernardino (108), Riverside (79), Kern (64) Monterey (48), Fresno, Orange	IX, RO, blending	McFarland MWC, City of Pomona; Southern California Water Company; San Gabriel County Water District; CWS-Salinas; City of Fresno; Bakman Water Company; City of Garden Grove; City of Tustin
Nitrate + Nitrite as N	Los Angeles (80), San Bernardino (58), Riverside (31), Tulare (17), Ventura (13)		
Radioactivity			
Uranium	San Bernardino (46), Kern (38), Stanislaus (28), Riverside (28), Madera (20), Los Angeles (19); Monterey	IX, RO, lime softening, coagulation/ filtration	Cal Water, Lakeland; CWS-Salinas
Volatile Organic Chemicals			
Carbon tetrachloride	Los Angeles (95)	granular activated carbon (GAC), packed tower aeration, blending[3]	San Gabriel Valley Water Company; City of Monterey Park; La Puente Valley CWD
1,2-Dichloroethane	Los Angeles (90), El Dorado (10)		Southern California Water Company; La Puente Valley CWD
Methyl tertiary butyl ether (MTBE)	Los Angeles (6), Kern (5), Monterey, San Mateo, Madera		City of Santa Monica; Cal-Am WC – Montara; Riverview WD; CWS-V Salinas; Yosemite Spring Park Utility Company

Table 11-3 continued

Contaminant	Counties Affected (# of sources with detections)[1]	Types of Treatment Used	Examples: Water Systems to Contact for Additional Information
Tetrachloroethylene (PCE)	Los Angeles (152), San Bernardino (27), Sacramento (8), Kern (6), Fresno (5), Monterey		City of Burbank; San Gabriel Valley Water Company; City of Monterey Part; EPA-Whittier Narrows OU; City of Whittier; Southern California Water Company CWD-Salinas; La Puente Valley CWD
Trichloroethylene (TCE)	Los Angeles (196), Fresno (17), Riverside (14), San Bernardino (10), Butte		City of Burbank; City of Glendale; Cal Water Service Co, Chico; La Puente Valley CWD
Pesticides			
1,2-Dibromo-3-chloropropane (DBCP)	Fresno (121), San Joaquin (35), Tulare (35), San Bernardino (34), Madera	blending, GAC	City of Fresno; City of Clovis; City of Sanger; CalWater, Visalia; City of Lodi; City of Madera
Ethylene dibromide (EDB)	Fresno (15), Kern (11), San Joaquin (5), Madera	blending, GAC, packed tower aeration City of Fresno;	City of Madera
Unregulated Contaminants (No MCL) **Inorganic chemical**			
Perchlorate (MCL to be established—see DHS website for status)	Los Angeles (134), San Bernardino (80), Riverside (61), Orange (31), Sacramento (13), Tulare (8), Santa Clara (7)	IX, biological, blending	California Domestic WC; La Puente Valley CWD; City of Redlands; San Gabriel Valley WC-Fontana; City of Riverside; City of Colton; City of Rialto; So Cal Water Co., So San Gabriel; City of Morgan Hill
Semivolatile Organic Chemical			
N-Nitrosodimethylamine (NDMA)	Los Angeles (~5)	UV photoionization	San Gabriel Valley Water Company; City of Industry; La Puente Valley CWD
Volatile Organic Chemical/Pesticide			
1,2,3-Trichloropropane (1,2,3-TCP)	Kern (75), Los Angeles (29), Fresno (23), Tulare (18), San Bernardino (16), Merced (13); Riverside (7), San Joaquin (7), San Diego (6), San Mateo (5), Stanislaus (5)	see VOCs above	City of Burbank

[1] The numbers of sources are from the DHS database, including analyses reported 1994-2002 www.dhs.ca.gov/ps/ddwem/chemicals/monitoring/results94-02.htm except for MTBE, perchlorate, and 1,2,3-TCP, which are through 2003 www.dhs.ca.gov/ps/ddwem/chemicals/chemindex.htm. Arsenic data are from 2000-2002 www.dhs.ca.gov/ps/ddwem/chemicals/arsenic/newmcl.htm, and the NDMA estimate is from the narrative at www.dhs.ca.gov/ps/ddwem/chemicals/NDMA/history.htm. For "Regulated Contaminants" the number in parenthesis represents detections greater than MCLs. For "Unregulated Contaminants of Interest" the number represents overall detections. In general, counties with only a few detections are not included, unless an example of a water system providing treatment is provided in a particular county.
For more information on drinking water treatment technologies, contact the local DHS drinking water office (see the DHS website for office locations), or contact specific water systems that are addressing a contaminant problem.

[2] Arsenic currently has an MCL of 50 ppb. In 2006, compliance with a new federal MCL of 10 ppb is required. This will increase the number of sources will detections greater than the MCL from a total of about 70 80 to over 600.

[3] Some systems are or may be considering use of advance oxidation processes, such as ultraviolet, or ozone for VOC treatment.

Potential Benefits from Remediation of Groundwater

The potential benefits of remediating contaminated groundwater so the water can be used as a part of the available water supply are:

- An additional water supply is available that would not be available without remediation
- The cost of buying an alternative water supply is avoided
- Eventually, through the flushing action, the aquifer may be cleaned to the point that treatment is no longer required
- Treated groundwater may be blended with other water supplies to increase the total available water supply
- Groundwater from remediation projects and blended supplies that do not meet drinking water or other high water quality requirements may still be available to meet water needs that do not require such high quality water, thus increasing the overall water supply
- Groundwater basins are protected from other threats including additional contamination caused by plume migration, limits to the spatial and temporal flexibility of pumping within a basin, and limits to groundwater banking and conjunctive use within the basin.
- A supply is maintained that is used throughout the state to meet up to 40 percent of the state's water demand.

Potential Costs

The cost of remediating groundwater includes:

- Cost of characterizing the groundwater or aquifer, in terms of all the contaminants present
- Capital cost of the system, whether groundwater or aquifer remediation
- Operation and maintenance costs during the life of the project; remediation may be required for a long time.

Except for responsible parties reimbursed by the Underground Storage Tank Cleanup Fund (Fund), it is difficult to estimate the cost of cleaning contaminated sites. However, the Fund reimburses about $180 million annually to eligible claimants. It is estimated that major oil companies that have not been reimbursed are expending about $50 million to $100 million annually on their sites. Therefore, costs associated with the cleanup of all UST sites in California appear to easily exceed $300 million annually. The cost to clean up an individual UST site typically ranges from $100,000 to $200,000. The cleanup of UST sites that are also contaminated with MTBE is costing significantly more than the average, with reimbursements as high as the Fund limit of $1.5 million per site.

The cost of cleaning up non-UST sites is also highly variable. A site where solvent contamination has reached groundwater may require continuous pump and treat operation for decades and cost millions of dollars.

Based on cost data from the State Water Resources Control Board and the California Department of Health Services, Division of Drinking Water and Environmental Management, total groundwater remediation costs in California could approach $20 billion over the next 25 years. The estimate is based on current costs for remediation, estimated future costs for similar remediation, newly discovered contamination, and emerging contaminants.

Groundwater remediation also avoids the costs of losing the aquifer as a water supply. These avoided costs include:

- Cost of an alternative water supply
- Long-term foregone profits and taxes from businesses and activities that decide not locate in the basin because of water shortages
- No opportunity for development of residential areas because there is no water supply available
- Contaminant may spread further, requiring greater and more costly remediation in the future.

Major Issues Relating to Groundwater Remediation

Water Quality

Several groundwater quality issues complicate remediation efforts. The types and the concentration of the constituents vary from aquifer to aquifer. Contaminated water associated with a hazardous waste facility, Superfund site, and other sites may contain a variety of regulated and unregulated contaminants. Non-point source contamination such as nitrates or elevated levels of boron or salts in agricultural areas can be widespread in the subsurface and can leach into the groundwater from surface infiltration or rising groundwater levels. Contaminated water may be poorly characterized, in terms of the contaminants that are present and locating the dimension of the plume is costly. The sources of the contamination need to be found and eliminated (or the amount of contaminated discharge reduced), so that the groundwater basin can be cleaned. There is always potential for other contaminants being detected subsequently that could cause the need for additional treatment facilities.

Water Quantity

Lack of knowledge about the geometry and characteristics of the aquifer complicates groundwater remediation. Without this information it is not possible to develop a water budget for the remediation.

Costs of Treatment

Cost questions can impede groundwater remediation. Who will pay, who are the responsible parties, and what is the appropriate share for each responsible party? Groundwater treatment is expensive and it can take years or decades to remediate contaminated groundwater sites. Delays in implementing groundwater remediation while the contaminants spread can significantly increase the cost and time required for cleanup. This is especially true if long-term litigation is involved to determine responsible parties.

Recommendations to Help Groundwater Remediation

The following recommendations for State action can help protect groundwater quality and remediate when necessary to maintain California's water resources:

1. Provide additional funding where appropriate to help local agencies and governments implement remediation projects where no financially solvent responsible parties exist.
2. Identify the responsible parties, so that they can provide funding to build treatment facilities and operate and maintain them.
3. Provide technical assistance for remediation projects, particularly where no financially solvent responsible parties exist.
4. The State (SWRCB, RWQCBs, DTSC, DWR) should compile information on currently operating remediation projects, including:
   - Contaminant(s) involved
   - Amount of contaminant(s) in the aquifer that must be removed, which will require many more monitoring wells
   - Type of treatment
   - Expected length of operation of the treatment project, which is directly dependent on the data collected
   - Capital cost of the project
   - Annual operating and maintenance cost, including costs of waste disposal
   - Amount of groundwater treated per unit time
   - Seasonality of volume treated (the amount may vary seasonally depending on usage)
   - Number of wells extracting groundwater
   - Number of connections served
   - Measures that could have prevented the contamination
5. Provide local governments and local agencies with State assistance to implement source water protection measures based on the source water assessments that were completed as of 2003 to protect recharge areas from contamination to prevent future contamination.
6. Provide State assistance to local agencies to prevent contamination of recharge areas.
7. The State should develop techniques to inventory, model and evaluate feasible actions to improve the long-term availability of groundwater and the long-term quality of groundwater as a vital component of California's water resources for beneficial uses.
8. Local government and local agencies should limit potentially contaminating activities in areas where recharge takes place and work together to develop a sustainable good quality long-term water supply for beneficial uses.

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